2009 IEEE International Conference on Control and Automation
Christchurch, New Zealand, December 9-11, 2009
FrPT2.3

Digital Watermarking Multi-objective Optimization Based on Multi-wavelet

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Abstract—**In order to enhance the practicality of digital watermarking, watermark perceptibility and robustness must be ensured. Taking human visual system characteristics into account fully, a digital watermarking multi-objective optimization based on multi-wavelet method is proposed. It utilizes Sa4 multi-wavelet to embed digital watermark, chooses intermediate frequency in embedding digital watermark adaptively according to the size of every energy mass, and uses multi-objective optimization method based on genetic algorithm to optimize and adjust the embedded depth to obtain optimal effect. Experiments show the new algorithm we proposed not only is robust to attacks, but also ensures the quality of watermarking-embed image.**

I. Introduction

As an effective means to solve the problem of digital products copyright, digital watermarking has gradually become an international research hotspot. It can distinguish various identities such as author owner issuer user and so on and can distinguish the digital products with false replication as a result of the information about copyright protected and authentication being carried [1]. An effective digital watermarking must possess properties such as perceptibility, robustness, safety etc., but perceptibility and robustness is a pair of incompatible properties. Based on the theories such as computer science, information communications, signal processing and cipher etc, digital watermark synthetically utilizes their new conclusions through space domain method and transform domain method. And space domain method directly adds digital watermark in image space domain by some arithmetic, but transform domain method embeds digital watermark information in the image by changing coefficient values about the image transform domain, such as DCT, DWT and DFT arithmetic. If using the transform domain method, the image firstly is changed, and then watermark is embedded and detected in the transform domain. Transform domain method usually needs large computation, but can make the image processing influence decrease and embedded robustness increase, because various image processing such as compression and filter are implemented in the transform domain. Wavelet transform and analysis of image are utilized more and more widely, owing to good image processing characteristic in the wavelet domain, in which Multi-wavelet algorithms have become the main research directions because of its symmetry/ anti-symmetry, short support, high order vanishing moments and orthogonality. Moreover, since Sa4 Multi-wavelet has good multifilter properties (GMP), it can enhance the robustness [2].

Many existing digital watermarking algorithms choose the intermediate frequency in embedding digital watermark information to weigh perceptibility and robustness [3], but it reduces the robustness resisting many sorts of attacks such as JPEG lossy compression, filtering, shear and rotation etc.. In Lin et al. [4], after watermarking-embed image is transformed using DCT, digital watermarking is embedded into low frequency for enhance robustness, which sacrifices perceptibility. In Prayoth et al. [5], a digital watermarking optimizing algorithm is proposed to split the difference between perceptibility and robustness. In Fang et al. [6], a blind digital watermarking algorithm is advanced to implement the integrative optimization of digital watermarking in perceptibility and robustness by adjusting coefficient difference based on edge detection. In Fang et al. [7], the intermediate frequency is chosen in embedding digital watermark adaptively according to the size of every energy masses after Multi-wavelet is broken up, and the Signal-to-Noise of image and the similarity degree of digital watermark information are all upgraded.

In this paper, we utilize Sa4 Multi-wavelet to embed digital watermarking and use multi-objective optimization method based on genetic algorithm to dynamically adjust digital watermark embedded by different embedded coefficients. The experimental results show that the optimized algorithm has better effect and practicality by the offensive test comparison.

II. Multi-objective optimization algorithm

Many optimization problems in practical engineering are

Manuscript received April 1, 2009. This work was supported in part by Xiamen University national 211 3rd period project “three-dimensional communication and information-integrated intelligent technology” and Science and Technology Plan Project of Xiamen, China 3502Z20083028.

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multi-objective optimizing problems, and different objectives are generally contradictory. If a multi-objective optimizing problem has infinite non-inferior solution that will form a non-inferior solution set. As to the solution of practical problems, it is the only way to set the most satisfied non-inferior solution as the ultimate solution through the decision of decision-makers.

The ultimate solution is obtained mainly through 3 types of methods: 1) generation method which constitutes a non-inferior solution subset and finds a ultimate solution on the basis of the intention of decision-makers; 2) interactive method which gradually finds the ultimate solution by the dialogue between analysts and decision-makers instead of getting many non-inferior solution; 3) linear weighted method which transforms multi-objective optimizing problems into single-objective based on relative important degree provided by decision-makers. In the paper, the last method is adopted [6], it seeks the approximate largest (smallest) value in the following function [8]:

$$F(x) = \alpha_1 f_1(x) + \alpha_2 f_2(x) \ldots\ldots + \alpha_n f_n(x) \qquad (1)$$

where α_i (i=1,2,…..n) is the set of supposed weights for each objective representing the important degree.

The difficulty of such problem is how to set up weight of various optimizing objectives consistent with the intention of decision-makers, so we subjective combine determining weights with objective, and (1) is transformed into:

$$F(x) = \beta_1 w_1 f_1(x) + \beta_2 w_2 f_2(x) \ldots\ldots + \beta_n w_n f_n(x) \qquad (2)$$

where β_i is the set of subjective weights and w_i is the set of objective weights. (i=1,2,…..n)

However, w_i which is usually got by AI or approximate estimated method is hard to obtain in practical engineering.

In the digital watermarking algorithm, the optimization of digital watermark perceptibility and robustness is the main target. And x is the smallest coefficient differences. The difference between two coefficients is adjusted to improve the robustness, and the value adjusted is the smallest coefficient differences. So the image quality function is

$$f_1(x) = a_1 x \qquad (3)$$

in which x is independent variable. Similarly, after the various attacks the approximate similarity function extracting digital watermark is

$$f_i(x) = a_i x \qquad i = 2,3,\ldots,n \qquad (4)$$

where a_1 is similar change rate in the image quality function and a_i is similar change rate of function derived by various attack experiments. To normalize the change rate, the objective weights is

$w_1 = |1/a_1|$, $w_2 = |1/a_2|$, ……, $w_n = |1/a_n|$

It is noteworthy that x varies in inverse proportion to the image quality, so a_1 is negative. Substitute the above results into the (2), the weighting fitness function for optimizing digital watermark perceptibility and robustness is:

$$F = (-1/a_1)\beta_1 Q + \sum_{i=2}^{n} \frac{1}{a_i} \beta_i NC_I \qquad (5)$$

where: $\sum_{i=1}^{n} \beta_i = 1$; β_1 is the subjective weight of image quality after digital watermark is embedded; β_i (i >=2) is the subjective similarity weight extracting digital watermark after some sort of attack; "I" is a sort of common digital watermark attacks such as compression, filtering, noise, etc.; NC_I is similarity extracting digital watermark after "I" attacks; and the greater the F, the higher the fitness, the more near optimal solution.

III. Digital Watermark Image Optimizing Method Based on Multi-wavelet

A. *Digital Watermark Embedding Algorithm [7]*

Compared with single wavelet, the multi-wavelet processing process is very complicated. And the multi-wavelet method must process signals in advance before change, which is core, root and base, what's more filter process in advance can eliminate irrelevant discreteness of multi-wavelet [9], at the same time, the multi-wavelet reconstruction can be completed after relative processes. The image decomposition process about multi-wavelet is organized as shown in fig. 1, firstly get four components after the row and column pretreatment, then do the multi-wavelet row decomposition or column decomposition for the four components separately.

Along with the rapid development of multi-wavelet, several multi-wavelet bases with higher performance are developed after the first multi-wavelet GHM. Sa4 multi-wavelet, one of the multi-wavelet bases, is adopted in the paper due to that it is orthogonal-symmetric or orthogonal-anti-symmetric and different from other kinds of multi-wavelet for a characteristic called GMP (good multifilter properties). GMP, a design standard of multi-wavelet, can be used to measure the

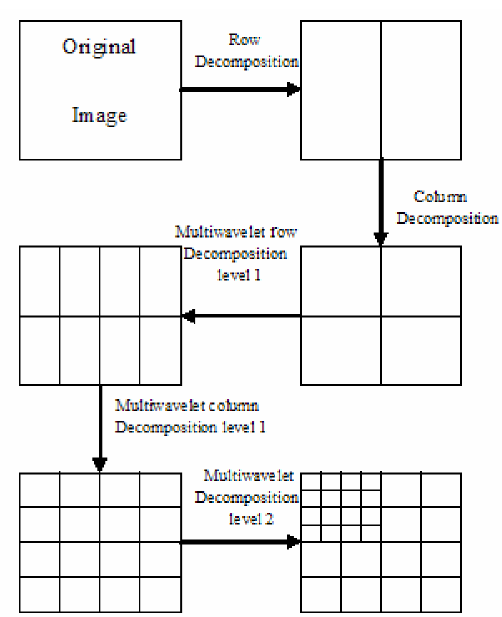


Fig.1 The image decomposition of multiwavelet decomposition

performance of multi-wavelet filter [10].

Digital watermark image optimizing method based on Sa4 multi-wavelet is:

1) After making the digital watermark image information into the one-dimensional sequence, a random number (key) is generated and then encrypted by disrupting sequence.

2) Preprocess the watermarking-embed image by Sa4 Multi-wavelet preprocessed method.

3) Make Sa4 Multi-wavelet transforming.

1	2	5	6
3	4	7	8
9	10	13	14
11	12	15	16

Fig. 2 Image after the multi-wavelet decomposition

4) Embed digital watermark into the intermediate frequency. In Fig. 2, the transformed image is divided into 16 parts, in which the parts 5-8 and 9-12 are the intermediate frequency positions from which the embedding position is selected. The high frequency information of the image suffers from the damage of attack technology like compression, which results in poor robustness; while the low frequency information has plenty of image characteristics, and can be perceived by visual organ easily. Therefore, according to the amount of the energy, 5-12 positions are in the intermediate frequency of the image. Two of the eight positions with middle energy can be selected for digital watermark embedding to keep balance of the robustness and imperceptibility. Here, calculate the sum of the absolute value of the energy of 5-12 parts and sort them by the first, and then select the middle two parts of the sorted results as the middle energy parts.

5) Adjust it utilizing pseudorandom sequence and adjust embedding depth by multiplying the coefficient k in the embedding process.

6) After the digital watermark embedding is completed, an image embedded digital watermark is got by anti-multi-wavelet transform.

B. *Digital Watermarking Extracting Algorithm*

1) Multi-wavelet transforms the image embedding digital watermark and original watermarking-embed image, compare in embedding position and extract digital watermark by

$$y_0(k) = \begin{cases} 1 & f_1(i,j) > f_0(i,j) \\ 0 & otherwise \end{cases} \tag{6}$$

where $f_0(i,j)$, $f_1(i,j)$ is the coefficient of original image and the digital watermark image in the (*i,j*) position after multi-wavelet transform, respectively; y_0 is the signal for extracting digital watermark.

2) Restore the correct sequence of y_0 by key and gain the digital watermark image.

The Normalized Correlation (*NC*) is defined to show the similar coefficient to the original digital watermark and the extracted digital watermark. *W(i, j)* is the pixels of original digital watermark; *W'(i, j)* is the pixels of the extracted digital watermark; M_1 and M_2 are the width and height of the digital watermark image [11].

$$NC = \frac{\sum_{i=0}^{M_1-1}\sum_{j=0}^{M_2-1} W(i,j) * W'(i,j)}{\sqrt{\sum_{i=0}^{M_1-1}\sum_{j=0}^{M_2-1} W(i,j)^2 * \sum_{i=0}^{M_1-1}\sum_{j=0}^{M_2-1} W'(i,j)^2}} \tag{7}$$

C. Digital Watermark Image Optimization Based on Genetic Algorithms (GA)

1) Determine the parameter sets of the actual question and obtain the optimizing solution of the digital watermark embedded depth *k*.

2) Code the digital watermark embedded depth *k* and the real-coding is adopted here.

3) After real coding, a well-distributed initial string data structure can be generated, which composes an initial population. If a larger initial population is selected, more points can be searched in the search space, so the global optimal solution can be found easily; but it increases the iteration time. According to the results in many simulation experiments and the algorithm performances, size 10 is selected.

4) (5) is the fitness function, so various results will enter into (5) as parameters in the digital watermarking embedding, digital watermarking attack and detection algorithms.

5) Implement crossover algorithm matching individuals based on pairwise matching principle, which adopts part arithmetic crossover.

6) Implement mutation algorithm retaining the best individual in accordance with the individual fitness size. If the mutation probability is smaller, it is difficult to generate the new model and premature convergence easily emergences, and on the converse, the algorithm will become a random search algorithm. So the mutation probability is set 0.08 in the paper.

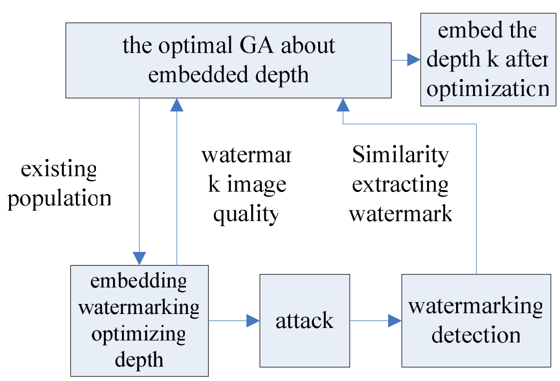


Fig. 3 Digital Watermark Image Optimization Based on GA

7) Implement non-consistency selection algorithm and the outstanding individuals will be selected and retained as the parent in the next iteration.

8) The algorithm terminates after 15 iterations in accordance with many experimental observations, or else turn to step *4)*.

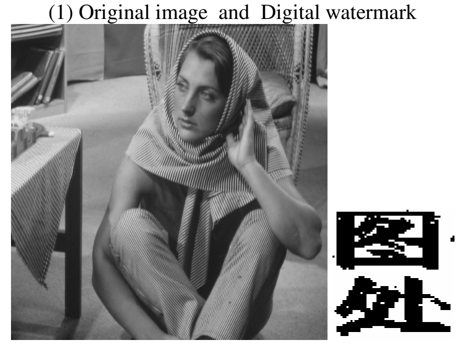
9) The optimized parameter sets will be generated after algorithm stop, which is the optimal solution or near optimal solution in the actual problem.

The specific process of the algorithm is shown in fig.3.

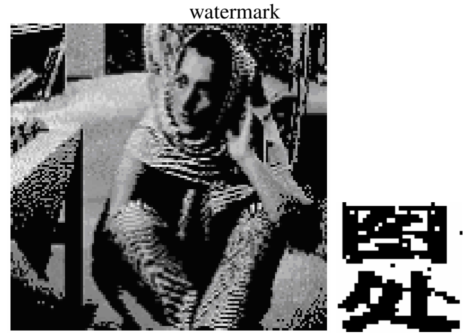
IV. EXPERIMENTAL RESULTS ANALYSIS

A 64×64 binary image is regarded as a digital watermark and original watermarking-embed image is a Barbara standard 512×512 image in the fig. 4 (1)(2). *NC* is digital watermarking

(1) Original image and Digital watermark



(2) Digital watermark image and Direct extracted digital watermark



(3) Digital watermark image after compression and Extracted digital watermark after compression

Fig. 4 Extracting results of digital watermark

extracting similarity after 50% JPEG compression. Based on section 2, after uniform sampling of x, approximate objective weight is obtained: a_1=-40，a_2=3.7. β_1, β_2 is the subjective weight of digital watermark watermarking-embed quality and similarity extracting digital watermark after compression, respectively. And, $\beta_1 = \beta_2$ =0.5 is supposed. When the Barbara image is compressed, the depth is obtained, k=1.0332. The digital watermark extracted from compressed image is shown in the fig. 4(3); optimal track with GA opposing compression robustness is shown in fig. 5. Finally, the smallest coefficient difference is obtained: x=24.6.

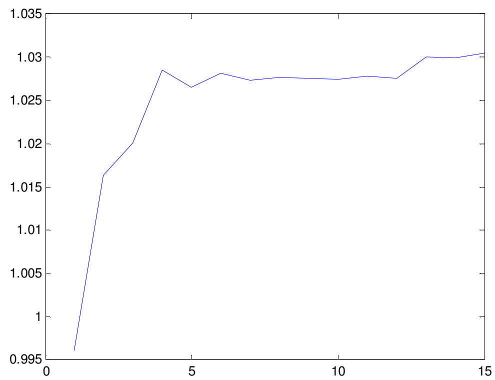


Fig. 5 GA optimal track
(Abscissa represents the iteration of population evolution in GA, and ordinate shows optimal fitness W in each generation.)

A. *Anti-attack Performance Analysis*

In the table Ⅰ, the similarity of extracted digital watermark is shown after JPEG compression at the different compression ratio. It can be seen that there is still 93.51% better similarity when the original image pixels is compressed down to 30%, which shows the method can resist commendably JPEG compression. Table Ⅱ is the similarity of the original digital watermark and digital watermark in different attacks. It can be seen that the method all can maintain the good resistance against various attacks. Apart from Gaussian filtering and multiplicative noise, the other similarities in various statuses are more than 92%.

TABLE I
OPTIMIZED ANTI-JPEG COMPRESSION EXPERIMENTAL RESULTS

Compression ratio	10%	30%	50%	70%
NC	0.9974	0.9880	0.9731	0.9351

TABLE II
OPTIMIZED EXPERIMENTAL RESULTS AGAINST OTHER ATTACKS

Attack	Median filter (3×3 template)	Gaussian filtering (0.5 standard deviation，3×3 template)	Laplace filtering (take reverse results)	Salt and pepper noise (strength 0.05)	Multiplicative noise (strength 0.05)	Poisson noise
NC	0.922	0.867	0.982	0.931	0.893	0.964

When k=1.0332, similarities of extracting digital watermark both are 0.9940 after fig. 6(1) and fig. 6(2) two sort of attacks. The experiments suppose $\beta_1 = \beta_2$ =0.5 and their results shows the algorithm in the paper ensures the quality of digital watermark image and maintains the good robustness against various attacks, so it well split the difference between perceptibility and robustness.

(1)

(2)
Fig. 6 Optimized anti-shear experimental results

B. *Algorithm Analysis and Comparison*

The fig. 7 shows the comparison of the perceptibility and robustness in digital watermark among the algorithms in the paper (GA_emd for short), DCT intermediate frequency embedded algorithm (emd1 for short) and single wavelet DWT algorithm (emd2 for short).

From the experiments , as to the emd1, the poor digital watermark robustness of anti-compression is taken on ,and though its image effect after embedding digital watermark information is slightly higher than GA_emd, its extracted digital watermark information obviously distort, but the digital watermark robustness in GA_emd algorithm is still strong in the 50% JPEG compression. As to the emd2, the embedded digital watermark image obviously distorts because of salt and pepper noise, which can easily obtained in the SNR comparison of image peak. By contrast, GA_emd controls salt and pepper noise, thus the image quality is almost as good as the original image and the perceptibility is obviously superior. And the extracted digital watermark information also has a relatively good similarity degree. Overall, GA_emd has better balance on perceptibility and robustness as well as higher practical value.

V. CONCLUSION

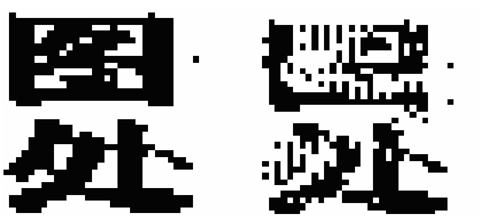
Digital watermark as an important technology of copyright-protection integrates computer science, information

(1) Original image PSNR=111

(2) Emd1 PSNR=34.1474

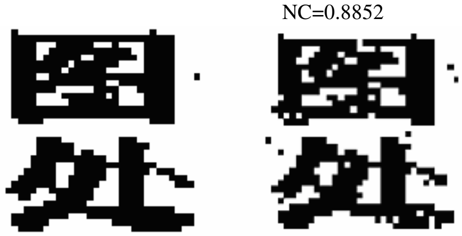
(3)Emd2 PSNR=26.9440

(4) GA_emd PSNR=32.81



(1) Original digital watermark

(2) Emd1 NC=0.8852



(3) Emd2 NC=1

(4) GA_emd NC=0.9731

Fig. 7 The embedded image and digital watermark information image respectively by emd1, emd2 and GA_emd algorithm

technology, cryptography and others, has wide application in file encryption, information security, and other aspects. However, Application range of digital watermark will be expanded and technical means will be improved in future. Imperceptibility of images and robustness of abstracting digital watermark are still important criterion of judging digital watermarking algorithm. The digital watermarking multi-objective optimization method proposed in the paper utilizes Sa4 multi-wavelet to embed digital watermark, and uses multi-objective optimization method based on genetic algorithm to optimize and adjust the embedded depth to obtain optimal effect. Experiments show the new algorithm we proposed not only is robust to attacks, but also ensures the quality of watermarking-embed image.

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